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STIMULATED RAMAN EMISSION AND ABSORPTION SPECTROSCOPY

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INTENSITY AND ⸍AIN MEASUREMENTS OF THE

STIMULATED RAMAN EMISSION IN LIQUID O_2 AND N_2*.

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ABSTRACT

In liquid O_2 and N_2 the threshold for stimulated Raman emission is found to be much lower than for other nonlinear processes. Thus it is possible to make reliable measurements of the intensity of Raman emission over a large range of incident laser power by using a simple longitudinal geometry. Several distinct regions of emission were investigated, including normal Raman scattering, exponential gain, onset of oscillation and saturation. There is good agreement with theory.

INTRODUCTION

It is well-known[1-3] that the comparison of theoretical
and experimental values of intensity and gain in stimulated Raman
emission is complicated by several competing processes such as
self-focusing, and Brillouin and Rayleigh scattering, all of which
may have similar appearance thresholds. Thus, anomalous intensity
behaviour in many liquids and even in gases[4-6] and solids[7] appears
to be the rule rather than the exception. One important con-
sequence is that the premature onset of oscillation has precluded
the observation of the expected exponential gain in most materials
with the exception of gaseous hydrogen and liquid acetone and
carbon tetrachloride[8]. Bloembergen and Lallemand[3,6] have over-
come some of these difficulties by the use of a Raman amplifier
and have demonstrated its importance in obtaining reliable values
of the Raman gain. Other useful experimental arrangements in
such studies include, the transverse resonator of Dennis and
Tannenwald[9], the off-axis resonator of Jennings and Takuma[10]
and the diffusely pumped amplifier of Bortfeld and Sooy[11]. More
recently, Shapiro, Giordmaine and Wecht[12], Bret and Weber[13], and
Kaiser and Maier[14] have shown that with picosecond and sub-
nanosecond laser pulses stimulated Raman scattering is the domin-
ant nonlinear scattering process in several liquids and thus
have obtained good agreement with theoretical intensities.

The present investigation of laser stimulated Raman emission from liquid O_2 and N_2 arose from the results of earlier studies of the spectra of the normal and stimulated scattering. In one, it was shown that the linewidth of the normal Raman scattering was exceptionally narrow indicating a large Raman gain[15]: in another, concerning the stimulated Raman emission, extremely sharp spectral lines were observed (Fig.1) without any evidence of broadening[16], thus indicating that self-focusing and other scattering processes were not prominent. From these results we concluded that possibly the threshold for stimulated Raman scattering is lower than for the competing precesses, in which case liquid O_2 and N_2 would be ideal substances for experimental study. Indeed, the present investigation has shown that liquid O_2 and N_2 are unique in this respect and no self-focusing or stimulated Brillouin scattering has been detected up to the highest incident laser power.

We wish to report our observations of the intensity of Raman Stokes radiation corresponding to the vibrational frequencies 1552.0 cm^{-1} and 2326.5 cm^{-1} of liquid O_2 and N_2 respectively. A simple longitudinal arrangement was used. The range of Raman intensity measurements includes the normal emission which varies linearly with incident laser power, a region of exponential gain over several orders of magnitude, the onset of oscillation with feed-

back by Rayleigh scattering and finally a region of saturation
and depletion. The observed gain is in good agreement with
that calculated from our experimentally determined cross-
section for scattering.

APPARATUS AND EXPERIMENTAL PROCEDURE

The exciting source was a giant-pulse ruby laser with a
rotating prism at one end and at the other a plane parallel
reflector (~25% reflectivity) of Corning 2-58 glass which
served as a mode selector[16] and also as a filter. The radiation
was emitted in a single pulse of ~30 ns duration and in a single
(or nearly single) axial mode. Good reproducibility in the laser
pulse was obtained by firing the laser at constant power near
threshold, at regular (3 min.) intervals with the ruby at a
constant temperature (-10°C). This procedure also eliminated any
spatial drift of the laser beam at the distant spectrometer slit.

The temporal behaviour of a typical laser pulse is shown
in Fig. 2a. A study of the spatial intensity distribution of the
laser beam was made at a magnification of 20X and by photo-
graphing the beam after attenuation by neutral density filters.
This showed the presence of several intensity maxima (Fig.3a)
which increased the effective intensity of the laser beam to
twice the average intensity. Also, the laser radiation was
found to be plane polarized to better than 2000:1.

The longitudinal arrangement shown in Fig.4 was used for

the measurements of Raman scattering intensity and state of
polarization, in the forward direction. The sample container was
a simple dewar of 1 litre capacity with a path length of 5.8 cm
between the two inner windows. It was positioned approx. 4 m
from the laser in order to reduce possible feedback of
scattered radiation to the laser. At each filling of the dewar
the liquid was passed through a 5μ millipore filter to remove
any dust particles. A short time after a filling, the liquid
became quiescent.

In order to increase the laser power density incident on
the samples, the beam diameter was reduced by a factor of about
10 (to 0.6 mm) with a system of two lenses. The incident laser
power was varied from 30 KW to 600 KW by inserting calibrated
neutral density filters of glass in the beam at the entrance
diaphragm D_1 and lens L_1. The laser pulse was monitored with an
EG & G photodiode (SGD-100) and displayed on a Tektronix 555
(or 519) oscilloscope. An essentially parallel laser beam was
incident on the sample. The radiation scattered in the forward
direction was collected through the exit diaphragm D_2 and
focused on the slit of the spectrometer. The laser light enter-
ing the spectrometer was attenuated with calibrated filters. A
grating spectrometer (Spex 1700) having a dispersion of 10 Å/mm
was used with both entrance and exit slits open to 3 mm. Measure-
ments of Stokes intensities were made with an RCA 7102 Photo-

multipler having a cooled photocathode ($-10^{\circ}C$). The signal
was amplified 40 times by a two-stage emitter follower and fed
into a type L preamplifier of the oscilloscope. The pulse
heights from the oscilloscope traces gave an effective measure-
ment of the intensity of Stokes emission during each laser pulse.
Brief studies of the laser and Stokes pulse envelopes were made
with a fast photodiode (ITT FW 114A) and a Tektronix 519
oscilloscope. Depolarization measurements were carried out with
a Nicol prism placed at the slit of the spectrometer.

Several precautions were taken to reduce any stray light
and to minimize its effect on the intensity measurements,
especially of the low intensity normal Raman scattering. The
main sources of unwanted stray light were found to be the laser
flashlamp, and optical filters and lenses of glass along the
laser beam which emitted relatively intense fluorescence radiat-
ion. Thus, all of the optics and sample dewar were enclosed in
a light-tight box having a 6 mm entrance aperture; diaphragms
were placed along the laser beam path in front of lenses; and
quartz lenses were used instead of glass lenses to minimize the
fluorescence. Finally, the effects of the broad band
fluorescence were suppressed by the use of a high dispersion
spectrometer.

For each liquid, the intensity measurements were carried
out in two stages. In the low intensity region of the normal

Raman scattering, the light collecting cone was 1.45×10^{-3} ster. for N_2 and 5.80×10^{-4} ster. for O_2. Calibrated filters were inserted in front of the spectrometer slit to cover the intensity range. In the high intensity region of stimulated Raman emission the light collecting cone was smaller, being 1.30×10^{-4} ster. for both N_2 and O_2. Again, calibrated filters were used to make intensity measurements over approximately ten orders of magnitude. The laser pulse energy was measured with a calibrated thermopile (TRG 100). The many optical filters used to attenuate the laser and Raman radiation were calibrated spectrophotometrically (Beckman DU) each to an accuracy of 3%. The transmission characteristics of the spectrometer and the sensitivity of the photomultiplier were measured over the required wavelength region (and for light of parallel and perpendicular polarization) using a NBS standard lamp.

An estimate of the possible errors in making absolute intensity measurements of the Raman scattering indicated an accuracy of ±50%, the main source of error arising from the many filters used in attenuating the laser radiation. However the accuracy of relative intensity measurements was considered to be better than ±30%.

BRIEF RÉSUMÉ OF THEORY

The theory of stimulated Raman scattering has been developed by many authors, notably, Hellwarth[17], Bloembergen and Shen[18], Townes and co-workers[19] and Maker and Terhune[20]. They have shown that the stimulated Stokes emission grows exponentially from noise according to the relation

$$I_s(\ell) = I_s(0)e^{+g\ell I_o} \tag{1}$$

Here, $I_s(\ell)$ is the intensity of the stimulated Stokes emission, $I_s(0)$ is the intensity of the normal (spontaneous) Stokes emission, I_o is the incident laser power density, and ℓ is the length of the amplifying medium. The gain g is given by

$$g = \frac{2c^2}{\pi h n^2} \cdot \frac{N}{\Delta\nu(\nu_o-\nu_R)^3} \cdot \frac{d\sigma}{d\Omega} \tag{2}$$

In general, and in the present work, g represents the gain for radiation polarized in the same plane as the incident plane-polarized laser radiation. In Eq. (2), c is the velocity of light, h is Planck's constant, n the refractive index, N is the effective number of molecules per cm^3, $\Delta\nu$ is the normal Raman linewidth, $\nu_o-\nu_R$ is the frequency of the Raman line, and $d\sigma/d\Omega$ is the total differential cross-section per molecule per ster. for the one polarization.

The total differential cross-section, $d\sigma/d\Omega$ may be determined from absolute intensity measurements of the normal

Raman scattering. For plane polarized incident light, it is defined as

$$\frac{d\sigma}{d\Omega} = \frac{2^4 \pi^4}{c^4} \left[\frac{h}{8\pi^2 \nu_R} \right] \frac{d}{\mu} \cdot \frac{(\nu_o - \nu_R)^4}{1 - \exp(-h\nu_R/kT)} \cdot K\alpha'^2 (1 + \frac{7}{45} \frac{\gamma'^2}{\alpha'^2}) \quad (3)$$

according to the polarizability theory of Placzek[21].
Here ν_R is the frequency of the Raman-active molecular vibration, d is the degree of degeneracy of the vibration (=1 for the totally symmetric vibrations), μ is the reduced mass, k and T are the Boltzmann constant and absolute temperature, and α' and γ' are, respectively, the isotropic and anisotropic parts of the derivative of the polarizability with respect to the internuclear coordinate at the equilibrium position. The constant K is the local field correction given by[22]

$$K = \frac{n_s}{n_o} (n_s^2 + 2)^2 (n_o^2 + 2)^2 / 81 \quad (4)$$

where n_o and n_s are the indices of refraction at the laser and Stokes frequencies, respectively. In order to evaluate γ' and α' it is necessary to measure the depolarization ratio $\rho = I_\perp / I_{\parallel}$ = $3\gamma'^2 / (45\alpha'^2 + 4\gamma'^2)$. Here $I_\perp$ and $I_{\parallel}$ are the intensities of scattered light polarized $\perp$ and $\parallel$, respectively, to the plane-polarized incident light.

It may be mentioned that Eq.(3) is valid only when the frequency of the incident exciting light is far from the

main absorption bands of O_2 and N_2 which occur in the vacuum
ultraviolet region.

EXPERIMENTAL RESULTS AND DISCUSSION

The observed intensity of first-order Stokes
radiation over a range of incident laser intensity is shown in
Fig. 5 for liquid O_2 and in Fig. 6 for liquid N_2. For both
liquids, it was possible to investigate the Raman intensity
over a range of approx. 12 orders of magnitude, from the very
low intensity of normal scattering through a region of
exponential amplification and oscillation to an intensity
approaching the incident intensity, and finally saturation.
These results will be discussed below under the headings
(a) normal Raman scattering, (b) exponential gain, and
(c) oscillation and saturation.

(a) Normal Raman Scattering.

The region of normal Raman scattering is one of very
low intensity. Our measurements for O_2 and N_2 are given in
Fig. 7. Although the data show considerable scatter, it is
seen that there is a linear dependence of Raman intensity
on incident laser intensity, as expected from theory. The
slopes of the graphs of Fig. 7 were used to determine values
of the differential scattering cross-section.

As already mentioned the errors in making these

absolute intensity measurements are approx. ±50% whereas the
accuracy of the relative measurements is perhaps ±30%. Thus
the present method of determining the absolute Raman intensities
was checked by measuring the scattering for the 992cm^{-1} line of
liquid benzene and comparing the resultant value of the total
differential scattering cross-section $d\sigma/d\Omega$ with values measured
by other experimenters. This cross-section is related to
experimentally measureable quantities by the equation

$$\frac{d\sigma}{d\Omega} = \frac{P_R}{P_o} \frac{1}{N\ell\Omega}$$

Here, P_R is the Raman power for the whole line scattered into
the solid angle Ω and P_o is the corresponding laser power, N
is the density of molecules per cm^3 in the scattering medium
and ℓ is the path length (ℓ= 10 cm in our C_6H_6 experiment).
Some of the recent values of $d\sigma/d\Omega$, for benzene are shown in
Table I along with our value of $6.6 \pm 3 \times 10^{-30}$ cm^2 per
molecule per ster. It is seen that the most accurate values
are those obtained by Damen, Leite and Porto[23] with a He-Ne
laser and by Skinner and Nilsen[24] with an Ar^+ laser, which after
correction for the ν^4 frequency dependence, are in very good
agreement. We have therefore taken the value $d\sigma/d\Omega$ = 4.50 x
10^{-30} cm^2 for benzene (at λ = 6943Å) as a basis for our evaluat-
ions and have measured the ratio of the Raman intensities of the

2326 cm^{-1} line for N_2 and 1552 cm^{-1} line for O_2 relative to the
992 cm^{-1} for C_6H_6.

The results of these intensity measurements are given in
Table 11 along with measurements of the depolarization ratio ρ for
liquid O_2 and N_2. (We have also included values obtained for liquid
CS_2.) The measured values of $d\sigma/d\Omega$ and of ρ were used to calculate
values of $\alpha' = d\alpha/dr$, the rate of change of polarizability with
nuclear displacement, from Eq. (3) after applying the local field
correction K (Eq. (4)) and these are included in Table II. The
values $\alpha' = 1.6 \times 10^{-16}$ cm^2 and 1.35×10^{-16} cm^2 for liquid N_2 and
O_2, respectively, are the same as the values obtained for gaseous
N_2 and O_2 by Stansbury, Crawford and Welsh[25]. Our measured value of
ρ for liquid N_2 agrees with that measured in the gas by Cabannes and
Rousset[26], but our value of ρ for O_2 is considerably lower than theirs.
(b) Exponential gain.

Under the present experimental conditions, the region of
normal Raman scattering appears to hold up to incident laser powers
of $\sim 70KW$. At higher laser powers, both liquids exhibit regions of
exponential gain, as shown by the linear portions of the graphs
(plotted on semilog scales) in Figs. 5 and 6. For N_2 this region
extends over a range of three orders of magnitude and for O_2, four
orders of magnitude of Stokes amplification. These results repres-
ent stable regions of gain up to factors of at least e^6 and e^8 for
liquid N_2 and O_2 respectively.

Values of the gain, g (exp), were obtained from the slopes

of the linear portions of the intensity curves (Figs. 5 and 6).
These are given in Table III. Also listed for comparison are
calculated values of the gain, g(calc.). The calculated values
are based on the scattering cross-section $d\sigma/d\Omega$ evaluated here
and on the linewidths 0.067 cm^{-1} for N_2 and 0.117 cm^{-1} for O_2
measured by Clements and Stoicheff[15], making use of Eq. (2).
It is seen that the values g(exp) and g(calc) are in good agree-
ment.

(c) Oscillation and Saturation.

    For both liquids, the regions of exponential gain are
abruptly terminated as shown by the discontinuity in slope of the
Stokes intensity curves, Figs. 5 and 6. These sharp changes in
slope represent the onset of Raman oscillation with a rapid rise
in output power. The oscillation threshold for N_2 occurs at
somewhat lower laser power than for O_2, 0.13 MW compared with
0.16 MW for O_2. These values were not significantly affected by
tilting the dewar with respect to the incident laser beam or by
the prescence of ice particles in the liquids (although in the
latter case the experimental error was greatly increased). The
onset of oscillation is therefore not considered to arise from
reflection at the windows or from scattering by bubbles or dust
or ice particles. Also, we have experimentally ruled out the
possibility that the rapid rise in output power is caused by
self-focusing. Near-field photographs of the laser and Stokes

radiation at the exit window show no evidence of filament form-
ation and uniform Stokes emission over the beam cross-section
(Fig.3b). No filaments were observed up to the highest laser
power used, 1 MW, where the self-focusing length is calculated
to be 5 cm for O_2 and 9cm for N_2. The critical power for self-
focusing[27, 28] calculated from the known Kerr constants[29] is 200KW
for O_2 and 600KW for N_2. The observed onset of oscillation occurs
at lower laser powers as mentioned above. Moreover, the ratio of
laser power at threshold of oscillation in O_2 to that in N_2 was
measured to be 1.20±0.006 as compared with the ratio of 0.3 for
the respective critical powers for self-focusing.

We believe that the most likely cause of oscillation is
feedback of Stokes radiation scattered in the backward direction
by Rayleigh scattering. This is suggested by the high Raman gain
for these liquids and by the ratio of 1.2 for the gain constants
of O_2 and N_2, which is the same value as the ratio of laser power
for oscillation. The Rayleigh scattering intensity determined by
Stansbury, Crawford and Welsh,[25] for gaseous O_2 and N_2 together with
the local field factor for the liquids leads to a feedback factor
of $\rho d\sigma/d\Omega$ (Rayleigh) = 6.1×10^{-6} per cm per unit solid angle for
liquid N_2 and 6.6×10^{-6} units for O_2. For the effective solid
angle of our experiments ($\sim 10^{-4}$ ster.) the feedback factor is
approx. 10^{-9} per cm, which is sufficient to explain the onset of
oscillation.

In the region of oscillation the rise in Stokes intensity is very steep and represents an increase of five orders of magnitude for liquid O_2 and seven orders of magnitude for liquid N_2.[6,30] The uppermost portions of the intensity curves (Figs. 5 and 6) are similar and indicate strong depletion of laser radiation and conversion to Stokes radiation. The oscilloscope trace in Fig. 2b shows a typical pulse of Stokes radiation in this region with the corresponding laser pulse severely distorted. This process results in the flat tops of the intensity curves and is the region of saturation. At still higher incident laser powers, the first-order Stokes radiation is converted to second-order Stokes (and anti-Stokes radiation) which results in depletion of the first-order Stokes intensity. This depletion is shown in the oscilloscope trace of Fig. 2c.

A brief study of the conversion of laser radiation to first-order Stokes radiation for liquid N_2 was carried out and the results are presented in Fig. 8. Here is plotted the ratio P_{out}/P_{in}, normalized for the laser radiation. The general behaviour of this ratio is in good agreement with the theory of Shen and Bloembergen[18]. Fig. 8 shows high conversion of approx. 75% laser radiation to first-order Stokes radiation in the saturation region.

CONCLUSION

This experiment has shown that liquid N_2 and O_2 are important materials for the study of stimulated Raman scattering. Because of their high Raman gain the stimulated Raman effect emerges as the dominant nonlinear process in these liquids. Thus it was possible to investigate the intensity characteristics and build-up of Stokes radiation over a range of 12 orders of magnitude, from the low intensity normal scattering through exponential amplification, oscillation and saturation and eventual depletion. A detailed study of the region of normal scattering and exponential gain shows very good agreement with theory. The regions of higher intensity also reveal the expected theoretical behaviour and warrant closer study. Finally, the high conversion efficiency of laser to Raman Stokes radiation indicates that these liquids are very useful as new frequency sources.

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Table I

Values of the total differential scattering cross-section for the 992 cm^{-1} Raman radiation of liquid benzene.

Authors	$(d\sigma/d\Omega) \times 10^{-30}$ $cm^2 sr^{-1}$	$(d\sigma/d\Omega) \times 10^{-30}$ corrected for 6943Å
Damen, Leite, Porto[23]	6.7±1.2 (6328Å)	4.5[a]
Skinner and Nilsen[24]	37.5±4 (4880Å)	4.95[b]
McClung and Weiner[22]	5.9±3 (6943Å)	5.9
Bret et al[2]	9 (6943Å)	9
Present authors	6.6 ±3 (6943Å)	6.6

[a] Calculated from $I\alpha(\nu-\nu_v)^4$, since the frequency of the exciting radiation, ν, is far from principal absorption frequencies. The Raman vibrational frequency is ν_v.

[b] Calculated from $I\alpha(\nu-\nu_v)^4/(\nu_a-\nu)^2$, since the frequency of the exciting radiation is near an absorption frequency, ν_a.

Table II

Values of the total differential cross-section, derivative of the

polarizability and depolarization ratio.

Liquid	ν_v cm^{-1}	$\dfrac{(d\sigma/d\Omega)\ \text{Liquid}}{(d\sigma/d\Omega)\ C_6H_6}$	$(d\sigma/d\Omega) \times 10^{30}$ cm^2 sr^{-1}	$\alpha' \times 10^{16}$ cm^2	ρ
O_2	1552.0	0.056±0.017	0.250±0.075	1.35 (1.4)[6]	0.11±0.01
N_2	2326.5	0.041±0.012	0.185±0.055	1.60 (1.6)[b]	0.10±0.01
C_6H_6	992.2	1.00	4.5[a]	2.84	-
CS_2	655.6	2.03±0.60	9.1±2.7	2.91	0.17±0.02

[a] Value of Damen, Leite, Porto[23] corrected for 6943Å radiation

[b] Values given by Stansbury, Crawford, Welsh[25] for gaseous O_2, N_2

Table III.

Values of the Raman gain

Liquid	$(\rho d\sigma/d\Omega)10^8$ cm^{-1}sr^{-1}	$\Delta\nu$[a] cm^{-1}	$g(calc)10^2$ cmMW^{-1}	$g(exp)10^2$ cmMW^{-1}
O_2	0.45 ± 0.14	0.117	1.45 ± 0.4	1.60 ± 0.50
N_2	0.29 ± 0.09	0.067	1.70 ± 0.5	1.60 ± 0.55
C_6H_6	3.06	2.15	0.28	-
CS_2	7.55	0.50	2.4	-

[a] Values of linewidths measured by Clements and Stoicheff.[15]

Figure Captions

Fig. 1. Stimulated Raman spectra of liquid O_2 and N_2 showing the first-order Stokes vibrational lines at 1552.0 and 2326.5 cm^{-1} respectively. The resolving power of the grating spectrograph is 10^5.

Fig. 2. (a) Typical laser pulse monitored with an ITT FW114A photodiode and displayed on a Tektronix 519 oscilloscope. (b) Typical first-order Stokes pulse obtained in the saturation region, and the corresponding depleted laser pulse at the right. (c) Same as (b) but with the Stokes pulse also showing some depletion at higher laser power.

Fig. 3. Near-field patterns showing the spatial intensity distribution of the incident laser beam (a) and the first Stokes emission (b), magnified 20X. Mottled appearance of Stokes picture caused by laser attenuating filters.

Fig. 4. Diagram of apparatus used for Raman intensity measurements. Explanation of symbols D-diaphram, A.F. - attenuating filter, G.G.-ground glass, P.D. - E.G. & G photodiode (SGD-100), L-lens, F-filter.

Fig. 5. Experimental curve for liquid oxygen showing Raman Stokes power as a function of incident ruby laser power.

Fig. 6.   Experimental curve for liquid nitrogen showing Raman
Stokes output power as a function of incident ruby
laser power.

Fig. 7.   Experimental measurements of normal Raman scattering
for liquids, benzene, oxygen and nitrogen.
(Experimental scatter results from very low light
levels used, necessitating a high amplification of
the photomultiplie signal.)

Fig. 8.   Experimental curves showing how the ratios of the
laser power (P_L) and the first Stokes power (P_s)
at the exit of the dewar, to the incident laser
power (P_{Lo}), vary with the incident laser power.
The dashed curve in the depleted laser region is
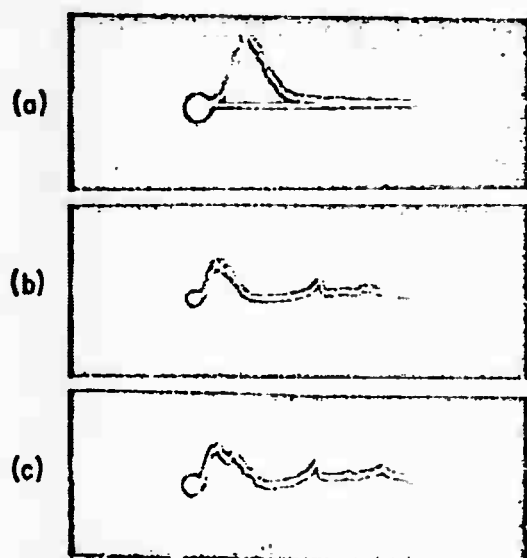only approximate as the laser pulse was severely
distorted.
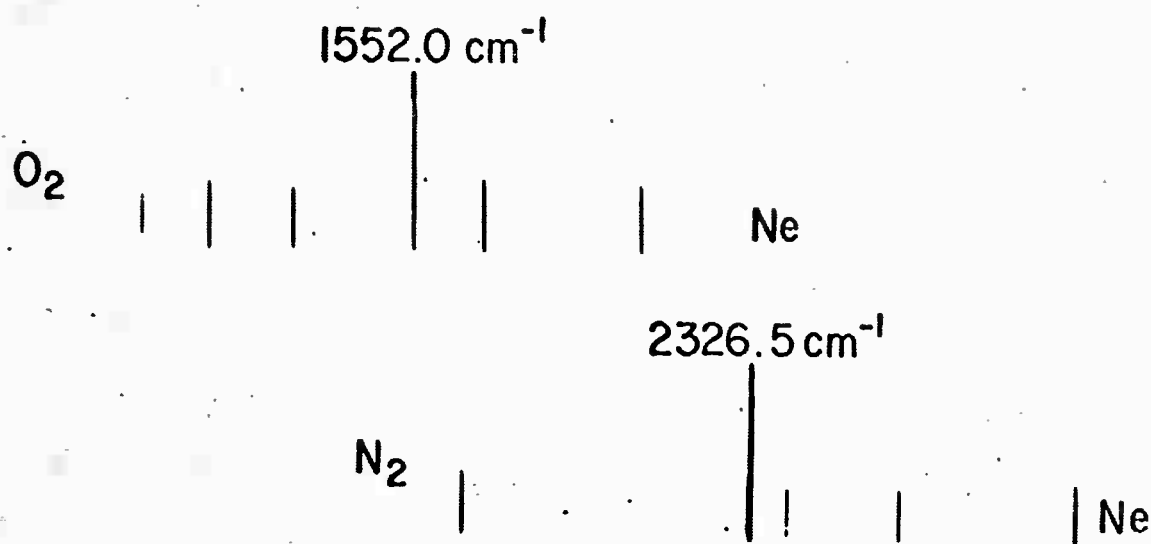
1552.0 cm⁻¹

O₂ | | | | | | Ne
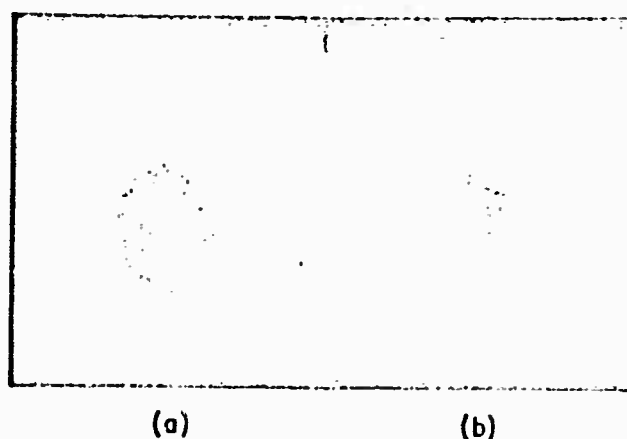
2326.5 cm⁻¹

N₂ | | | | Ne

FIG. 1.

(a)

(b)

(c)

100 ns.

FIG. 2.

(a)   (b)

FIG. 3.

LIGHT TIGHT BOX

RUBY LASER

A.F.

P.D.

D₁(d=0.6cm.)

L₁(f=50cm.)

A.F.

A.F. G.G.

P.D.

L₂ (f=5cm.)

DEWAR

D₂

L₃ (f=15cm.)

A.F. F

SPEX 1700

G.G.

R.C.A. 7102

I STOKES

I LASER

TRIGGERING SIGNAL

TEKTRONIX 555

J. CRUN 2-11

FIG. 5. CRANL-1-51
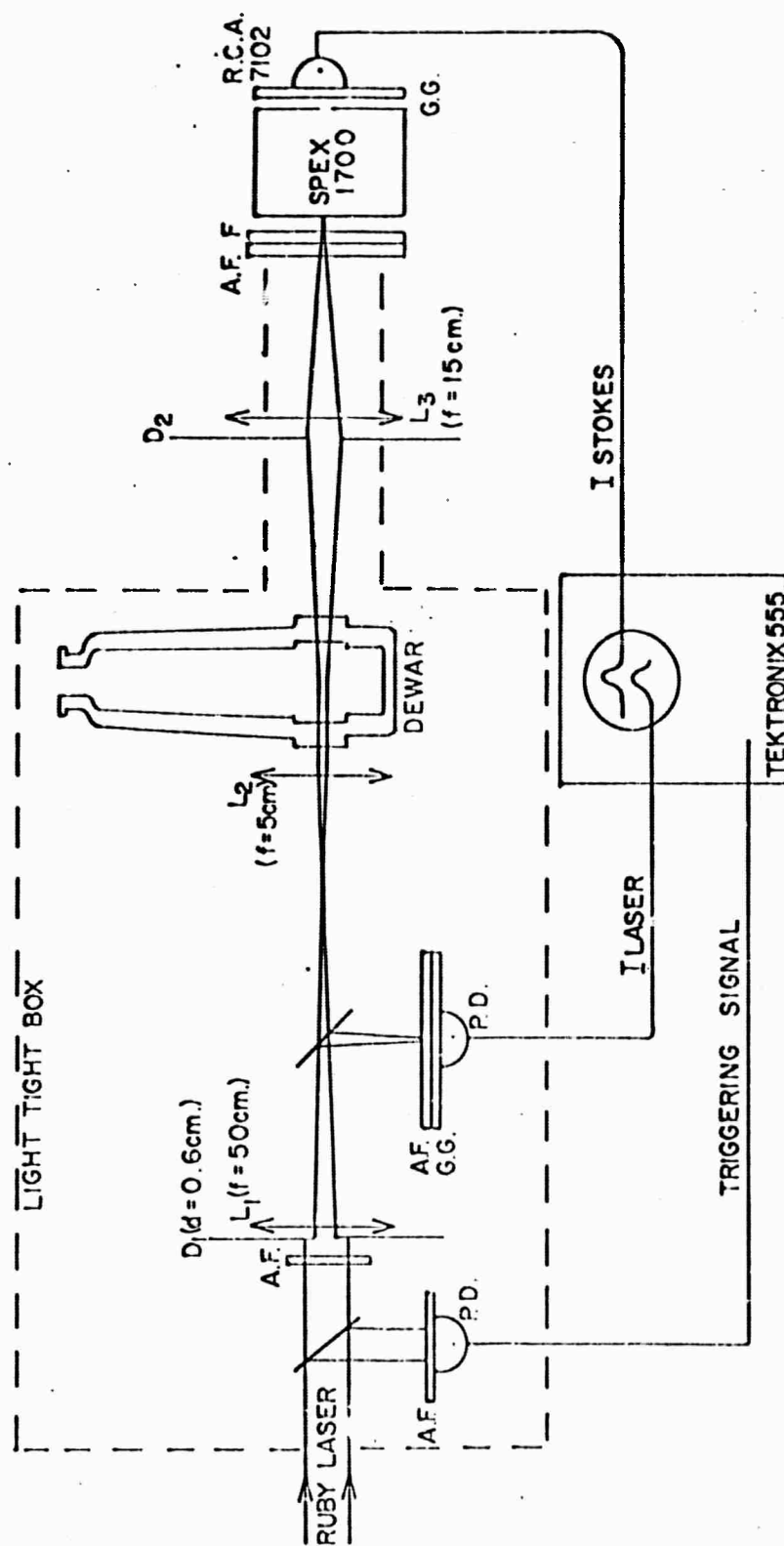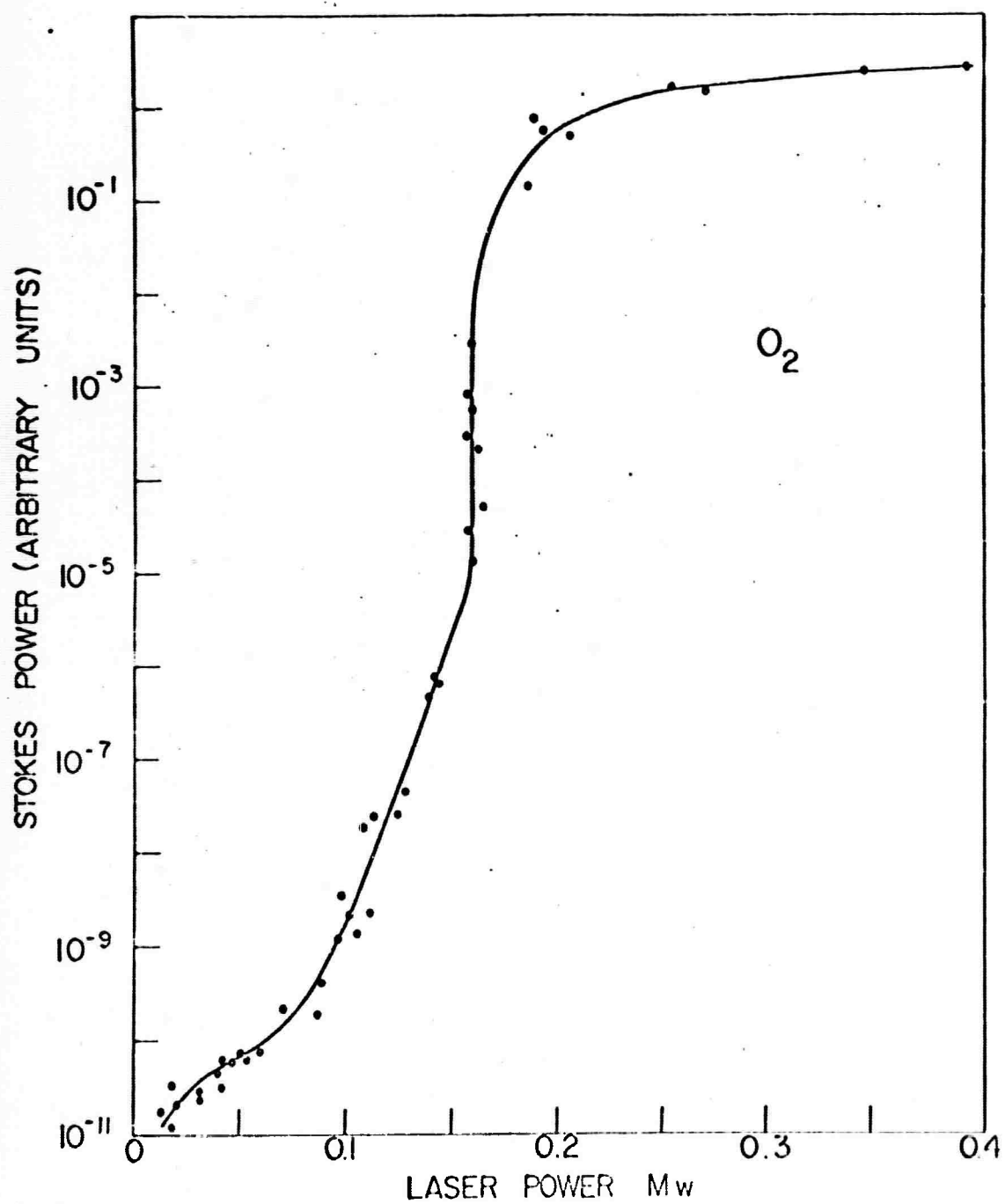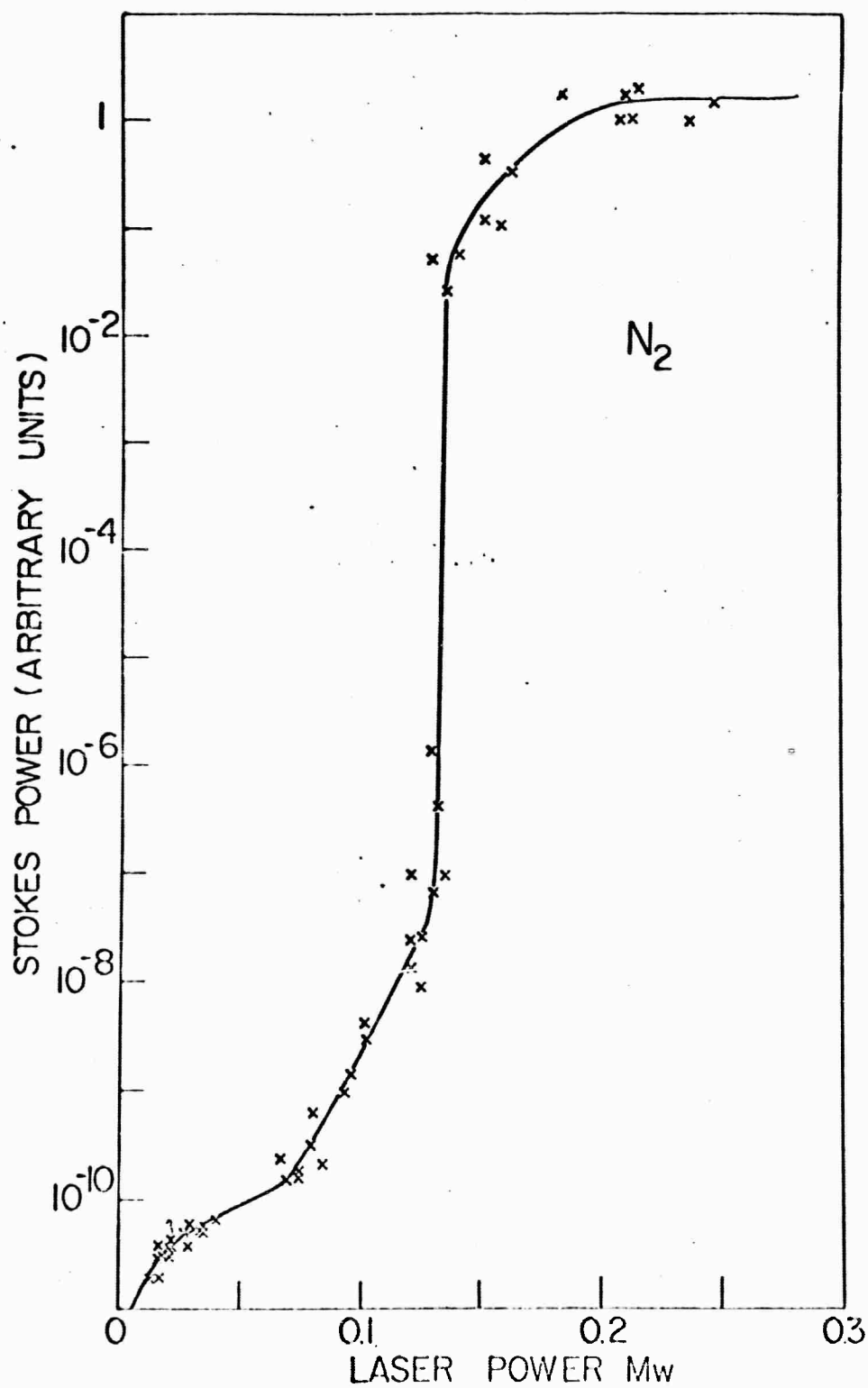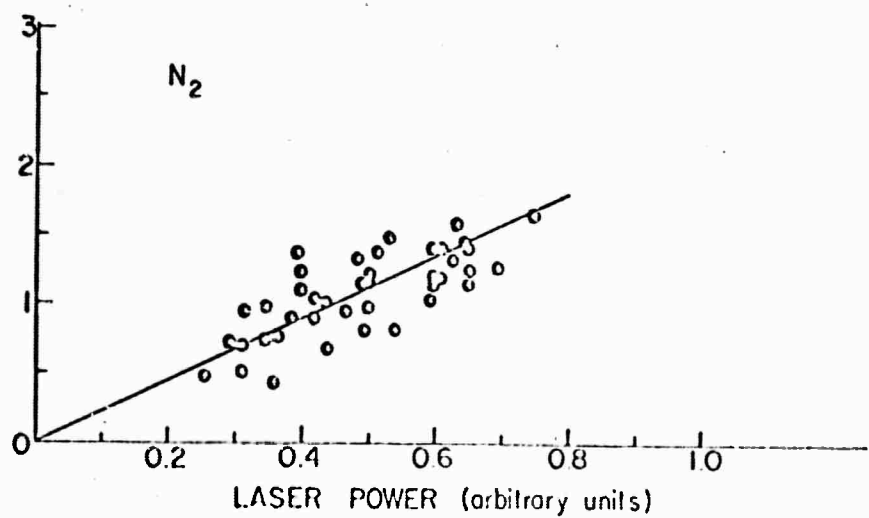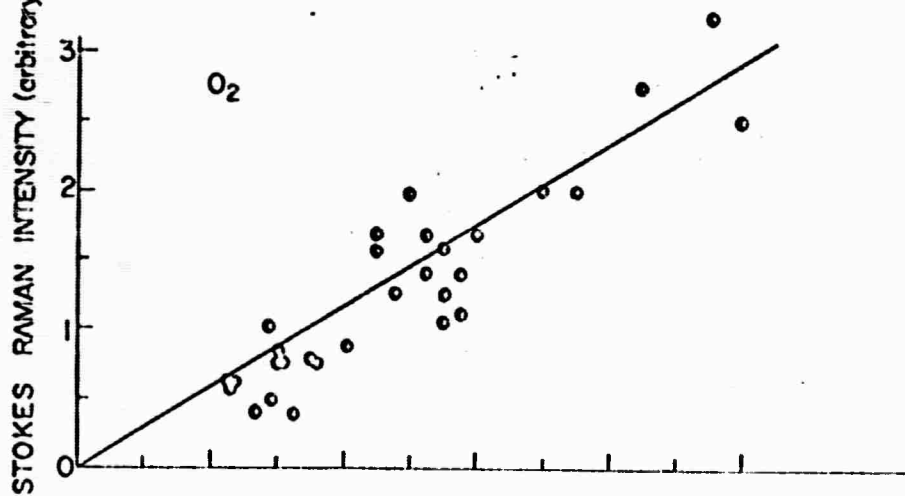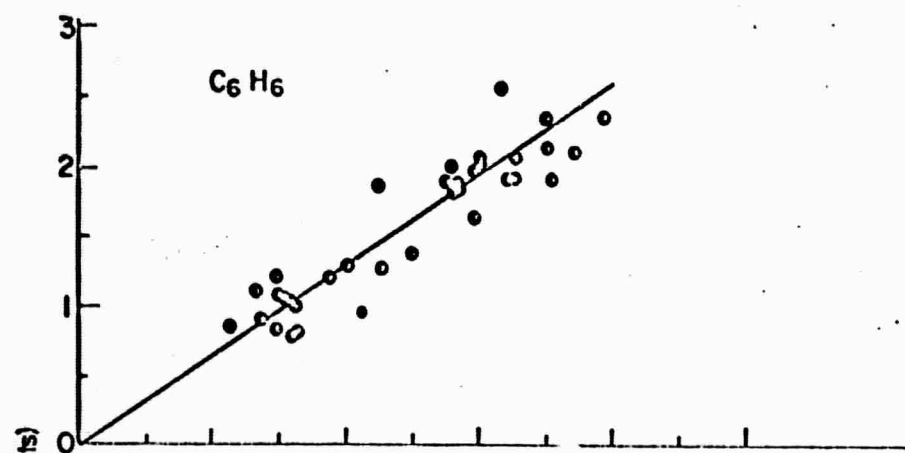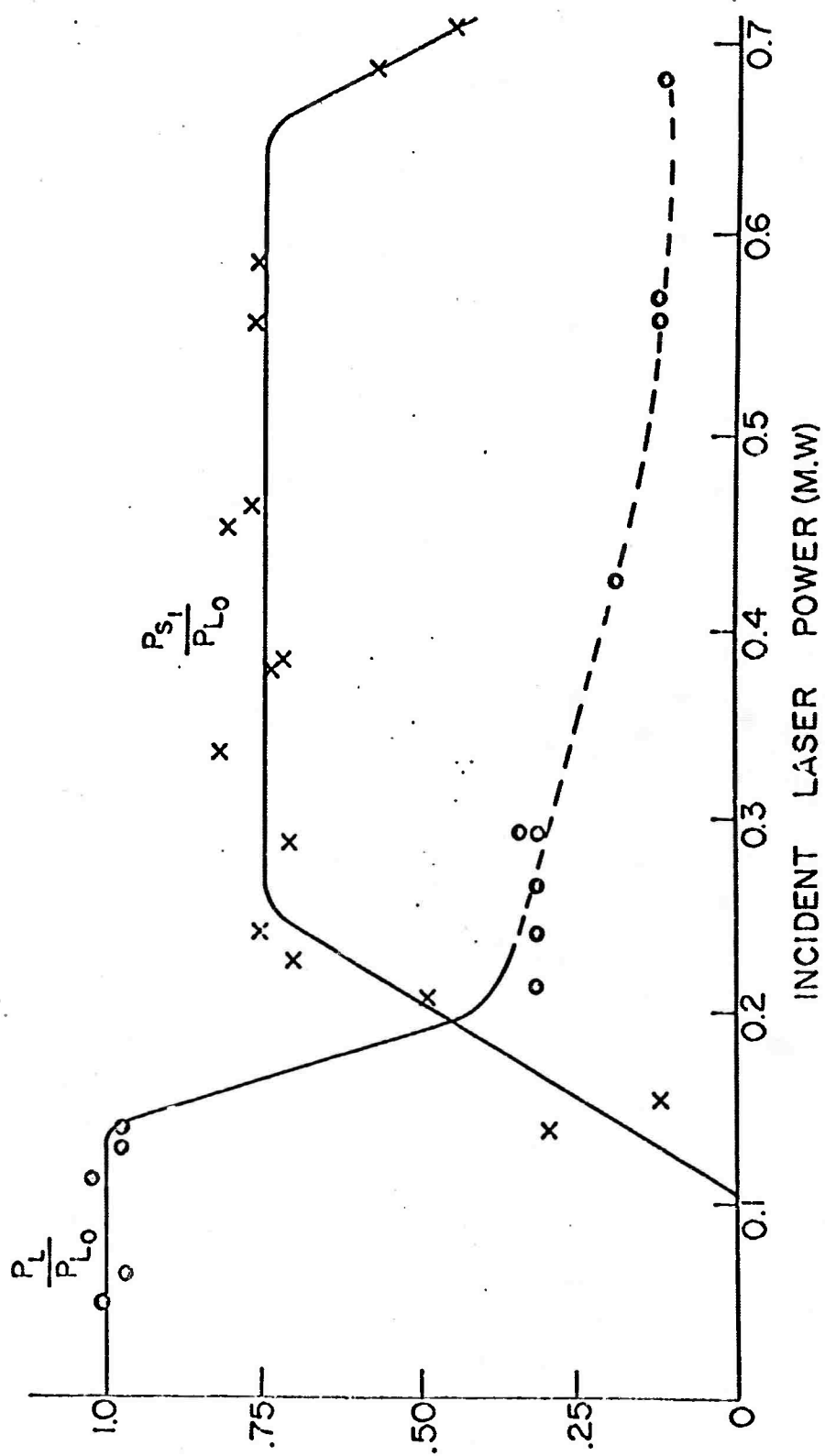
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1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
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3. REPORT TITLE

Intensity and Gain Measurements of the Stimulated Raman Emission in Liquid O_2 and N_2

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Semi-Annual Report No. 7 1 June 1968 - 1 January 1969

5. AUTHOR(S) *(Last name, first name, initial)*

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McQuillan, Archibald K.

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10. AVAILABILITY/LIMITATION NOTICES

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Office of Naval Research and Advanced Research Projects Agency

13. ABSTRACT

In liquid O_2 and N_2 the threshold for stimulated Raman emission is found to be much lower than for other nonlinear processes. Thus it is possible to make reliable measurements of the intensity of Raman emission over a large range of incident laser power by using a simple longitudinal geometry. Several distinct regions of emission were investigated, including normal Raman scattering, exponential gain, onset of oscillation and saturation. There is good agreement with theory.

DD FORM 1473
1 JAN 64

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Raman Intensity and Gain						
Stimulated Raman Emission in O_2 and N_2						
Raman conversion efficiency in liquid N_2						

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